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## TOWARDS A NEW GENERATION OF MISSION PLANNING SYSTEMS: FLEXIBILITY & PERFORMANCE.

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### ABSTRACT

This paper presents some new approaches which are required for a better adequacy of Mission Planning Systems. In particular, the performance, flexibility and genericity issues are discussed based on experience acquired through various Mission Planning systems developed by Matra Marconi Space.

**Key Words:** Mission Planning, Knowledge Based Systems, Flexibility & Performance.

### INTRODUCTION

The increasing complexity of modern spacecrafts, and the stringent requirement for maximizing their mission return, call for a new generation of Mission Planning Systems. Indeed, this complexity has several impacts on the :

- adequation of the specific planning & scheduling methods;
- performance problems;
- compliance with the eventual evolutions of the mission itself.

This paper presents the main lessons learned by Matra Marconi Space from several projects on Mission Planning, showing the benefits of advanced software techniques. They are illustrated by systems developed by Matra Marconi Space.

### PROBLEM DEFINITION

The term "Mission Planning" is used to refer to the process of planning and scheduling all

activities and operations of the space segment (spacecraft platform and payload, e.g. power sub-system for the platform, optical instruments and tape recorder for the payload) and the ground segment (ground station activities, payload data processing and product dissemination) associated to a given mission.

The main inputs to the Mission Planning System are a set of requests of the following types :

- Spacecraft platform operation;
- End User request (e.g. observation requests for an Earth observation satellite);
- Other types of ground segment activities (data processing, dissemination, etc).

The main outputs of the Mission Planning System are the *Service Utilization Plan* for satellite End Users, the *Final Operations Plan* uplinked to the space segment. Additional outputs include ground segments activities plans. From an operational point of view, the whole process is decomposed in the two following phases :

• Generation of the Operations plans : This phase is performed off-line and deals with the acquisition of User Requests and the detailed planning and scheduling of all space / ground operations. It includes :

- The generation of the Preferred Exploitation Plan (PEP),
- The integration of this first plan with the activities required by the Operations team for house keeping manoeuvres, and the production of the final "executable" plan.

• Execution of the Operations plans : Once the whole planning and scheduling process has

been completed, a schedule is available for execution and transmitted to the execution environment. During execution, monitoring is performed to control the evolution of the mission and detect eventual anomalies. If any disturbance on the current schedule occurs during its execution, rescheduling may be required and performed locally by the mission control center. If the rescheduling fails, a replanning session is entered on the Mission Planning System. Examples of anomalies include resource shortage (e.g. electrical power drop, unavailable ground station), activity execution failure (constraint violation, unexpected result), and changes in the satellite status due to some contingency (automatic or manual plan interruption, unexpected state transition).

## ADVANCED TECHNIQUES

Based on experience learnt from past developments and current studies, both on operational Mission Planning systems and on advanced prototypes, three main areas which can be improved using advanced techniques (e.g. Artificial Intelligence) can be identified :

### Algorithmic Performance

The Mission Planning problem is generally characterized by an intrinsically high combinatorial complexity, reflecting the complexity of the spacecraft itself and the numerous utilization constraints related to the resource usage, the inter-instruments constraints and the mission operational constraints. Taking the example of the Earth Observation missions, the planning process (typically performed on a daily basis) has to select an "optimal" set of candidate observation requests to be executed in the next day, among a set of pending requests which may be of the order of thousands. The generation of all the possible scenarii cannot be performed in a reasonable time. It is thus necessary to find powerful algorithmic techniques to deal appropriately with that complexity, in order to optimize as much as possible the utilization of the satellite, while taking into account the constraints on the available computing time.

Matra Marconi Space has conducted an internal study on this problem in order to evaluate the applicability of advanced algorithmic techniques on the planning & scheduling of an Earth Observation spacecraft. Generally, this type of spacecraft raises a complex planning & scheduling problem due to the high number of potential requests that can be submitted and also the hard operational constraints having strong impacts on the feasibility of the resulting plan. Thus, the objective of the study was to optimize as much as possible the use of the satellite resources with an acceptable response time taking into account the following points :

- On one hand, the combinatorial problem due to the high number of requests to be scheduled makes the determination of a good solution difficult in a reasonable time (large space of potential solutions to be explored);
- On the other hand, the complexity of the spacecraft due to the management of tape recorders, the strategy used for ground station dump operations and the constraints imposed by the capabilities of the instruments (e.g. transitions between image acquisitions) makes the determination of one feasible plan a time consuming step.

The activity performed in 1993-94 lead to the definition and implementation of a planning algorithm applied to the SPOT4 mission planning problem using an iterative and "any-time" optimisation strategy [1]. This approach is characterized by two phases :

- Phase 1 : Determination of a first plan (without optimization) based on a simple heuristic strategy. This phase is considered as an initialization phase being responsible for the determination of a first potential solution.
- Phase 2 (The anytime phase) : The algorithm starts a loop which explores the initial plan elaborated in Phase 1 and then optimizes this plan. This operation is done by iteratively removing some requests and inserting new requests according to heuristics driving the plan evolution toward a better plan quality. In order to avoid looping in the remove / insert process, all generated plans (up to several thousands) are stored and each new plan is checked against the history of the already generated plans. At any time, the "current plan" is defined as the best solution at hand,

with respect to the plan quality criteria as specified operationally.

This algorithm was integrated into a mission simulator for analysis on real problems. Testing has been performed using operational scenarios and the analyses conducted during the testing phase have allowed to demonstrate the following advantages of the approach :

- It tackles the problem globally, optimizing the solution with respect to the whole set of constraints, instead of handling separately the different constraints (this latter approach based on filtering mechanisms, by nature, always leads to sub-optimal solutions);
- A first plan can be made available at the end of the first phase, in a very short time;
- The initial plan is improved regularly and solutions are available at any time (Several plans of approximately the same "quality" are available);
- The flexibility of the iterative approach allows late insertion into the plan of new requests, which is an important advantage from an operational point of view.

This approach thus proved to be quite successful; furthermore, it is general enough to be reusable for other planning and scheduling problems. Further developments in this area now concern the application of these techniques to a new observation satellite.

### **Flexibility**

The lifetime of spacecrafts and the duration and complexity of the projects call for highly flexible and evolutive planning systems, enabling users to adapt the planning system to the evolutions of the planning problem. Indeed, the following cases can be envisaged :

- evolution of the spacecraft (e.g. degradation of the available power, degradation of the recorder capacity, equipments out of order, ...) : The definition of the spacecraft model reflecting the capabilities of its main components must be modifiable all along the mission since it influences the planning constraints related to the space segment.

- evolution of the ground segment : Modifications of ground segment may impact on the planning problem by adding or modifying constraints related to the ground segment capabilities. For instance, the post-processing of received data may be improved by new computer characteristics enabling the possible processing of more requests.

- evolution of planning strategies : The feedback of the mission is generally a source of experience that can be used to improve the spacecraft utilization and to better fulfill the objectives of the mission. This implies a lot of modifications on the planning & scheduling strategy to be used. This is particularly true at the early beginning of the exploitation.

In conventional Mission Planning System, information is more or less hard-coded, making changes and corrections difficult. For instance, the evolutions of conceptual information concerning strategies for resolving conflicts cannot be modified by the operator and requires software modification. In order to solve this problem, Knowledge Based Systems (KBS) have a more declarative approach which brings a high degree of flexibility in the system.

The following systems can be mentioned to illustrate this approach :

- PlanErs, dedicated to Mission Planning;
- Optimum, a more generic project planning & scheduling system.

### **PlanErs :**

PlanErs [2], [3] is a mission planning system developed by MMS (France), CRI (Denmark) and AIAI (University of Edimburgh) for the European Earth Resource Observation satellite ERS-1. It has been developed during an ESA R & D project from 1987 to 1990. Its first objective was the modelling of the planning & scheduling process in order to optimize planning strategies (usage of recorder, record / dump strategy and selection of the ground station dedicated to the dump operation, priority mechanism between requests in order to cope resource shortage, etc). It is implemented in Common Lisp on top of the

KEE [4] development shell which provides an object-oriented programming environment and graphic functions.

One of the main features of the system is the use of a high level, user accessible formalisms for representing the different areas of the planning knowledge.

The object oriented model of the satellite, the rules used for expressing planning constraints and strategies, and the associated syntactic editors, provide the users with an easy-to-use environment enabling them to modify the internal planning knowledge, for instance on the following aspects :

- operational constraints related to instrument usage (e.g. maximum usage per eclipse) : these rules have been frequently modified during the system experimentation in order to optimize instrument usage as well as power consumption;
- transition modes for instrument . An example is the following rule.

*From Mode Measurement\_1 to Mode Measurement\_2*

- *Goto Mode Standby\_1 during 10 seconds*
- *Goto Mode Standby\_2 during 20 seconds*
- *Goto Next\_Mode*

- rules defining the IDHT (recorder) strategy. These rules have been one of the main problems raised by the ERS-1 application. The challenge was to define a concept enabling to change interactively strategies concerning the transition between IDHT modes in order to optimize the recorder capacity as well as ensuring a good coverage of global zones, taking into account priorities. Due to the numerous events to be taken into account in the definition of these transitions (orbits, eclipses, ground stations, precise timing between events, transition duration), a specific rule formalism had to be designed. Using the syntactic editor, end-users have been allowed to modify the IDHT behaviour, modifying the chain of transitions according to the context. A specific effort has been made during the experimentation phase in order to increase the readability of this formalism, and in

particular to define a clear set of parameters to be taken into account during IDHT planning.

- power conflicts resolution rules : these rules are used when conflicts are detected on power usage. Here too, the difficulty was to define a set of parameters (e.g. Depth Of Discharge over the orbit N) and generic actions (reject a request, reduce a request, ...) to be taken into account during power verification and conflict resolution.
- other parameters : finally, the system includes a set of parameters characteristic of the planning constraints, such as the transition duration, the power consumption per instrument modes, the precise tape position table for the recorder, the available power from solar arrays,... All these parameters are user editable.

The flexibility offered by the system was originally limited to the transition rules but was extended during experimentation to cover operational constraints as the users identified the numerous possibilities offered by this feature. The possibility for the user to modify on-line various constraints and conflict resolution strategies, and see immediately the effects on the plan generated by the system, was a preponderant argument to the planers usage.

Figure 1 describes the Man Machine Interface of PlanErs.

Thanks to this approach, the PlanErs system has been used in 1991-1992 by the European Space Agency (ESA) as a Mission Analysis tool for interactively simulating the impact of various strategies and constraints on the mission output of the satellite. PlanErs also allowed to demonstrate a high benefit of Knowledge Based System techniques to deal with the problem domain evolutivity thanks to the very modular and declarative representation of the different types of knowledge involved in the scheduling problem.

PlanErs is going to be reused for the ERS-1 and ERS-2 mission analysis at ESA / ESRIN.

## Optimum :

Optimum [5] is a generic purpose planning and scheduling system that has been designed to handle complex problems in which plan quality, resource optimization and plan progress monitoring are key issues. Interactivity of the system enables the user to assess different planning scenarios and to take a decision in real-time. It was originally an R&D project for ESA/ESTEC developed in 1991-1992. Consolidated by Matra Marconi Space in 1993, it is now used for planning integration activities of the Ariane 4 Vehicle Equipment Bays. It is implemented in Common Lisp + the CLOS object system.

The comparative advantage of OPTIMUM, with respect to classical project planning systems, is its ability to capture information which describes the underlying logic of the plan, instead of using pre-defined sequences of activities. This allows the system to :

- verify the logic of the plan built or updated by the user;
- provide a rich formalism to describe the constraints of the domain;
- schedule activities and resolve resource conflicts.

Figure 2 describes the Man Machine Interface of OPTIMUM.

## Genericity

The need to reduce mission-specific software development costs requires to develop Generic Mission Planning functions, from which a mission-specific Mission Planning system can be derived at low cost. In this case, the use of an object oriented representation for both the spacecraft model and the definition of the planning and scheduling methods participate to the genericity of the planning system by offering a more natural and reusable decomposition of the planning & scheduling world and of the methods governing the planning process.

## GMPF :

This issue is addressed in the Generic Mission Planning Facilities (GMPF) project [3] which is currently performed by Cray Systems (UK) and Matra Marconi Space (France) for the European Space Agency (ESA/ESOC). The objective of this study is to analyze the commonalities between the large variety of Mission Planning Systems dedicated to specific missions and, by identifying the plan elements and the planning and scheduling process required by several types of mission, to define a common planning & scheduling kernel which can be easily customized to specific missions. The GMPF project should contribute to the definition of the new generation of Spacecraft Control Center (SCOS II) which is conducted by ESA / ESOC.

The envisaged types of missions are :

- Observatory Missions: The spacecraft has one main instrument. End Users are allocated observing time windows during which they have dedicated usage of the instrument.
- Survey Missions: The spacecraft has a single or a small number of payloads. The spacecraft and payload are normally operated by a centralised agency on behalf of a number of End Users who request specific observations that are planned according to a high level mission definition.
- Multi-Instrument Missions: The spacecraft has a number of independent experiments, each provided by a separate Principal Investigator (PI). The platform is operated by a centralised agency but PIs are responsible for operation of their experiments, submitting requests to the control centre.
- Telecommunication Missions: The spacecraft has a number of transponders to provide communications between ground stations (fixed service) or between another spacecraft and ground (data relay service). The spacecraft and its payload are operated by a centralised agency on behalf of the End Users. Transponders communication channels are allocated to Users.

The result of the GMPF study will be the definition and prototyping of :

- an objects library defining all the planning & scheduling elements and methods. These objects can be later reused or customized (by subclassing) for a specific application.
- a set of tools used to customize the library for a given application. These tools include :
  - a User Interface Builder based upon an existing commercial tool and complemented by dedicated widgets specific to Mission Planning functions. It is used to define the User Interface dedicated to the Mission Planner.
  - a Library Browser used to navigate in the classes hierarchy and dedicated to the software developer to pick up software components to be used in a specific application.
  - a Mission Specific Information Editor used to defines all the parameters which are normally fixed for the whole mission but can evolve due to modification of the space / ground segment.
  - a Rule / Constraint Editor used to provide the Mission Planner with the capability to define and edit rules and constraints using templates (e.g. syntax driven editor). This tool is used during the mission lifetime.

At the current stage, the definition of the users requirements for the GMPF library / toolset has been performed leading to a first specification of the main object classes (and attached informations) to represent data (plans, schedules, activities, etc) and knowledge (constraints, planning strategies) relevant to the planning process.

This project will be completed at the end of 1995, and will lead to the implementation of a prototype of the GMPF and of a mission specific demonstrator.

## CONCLUSIONS

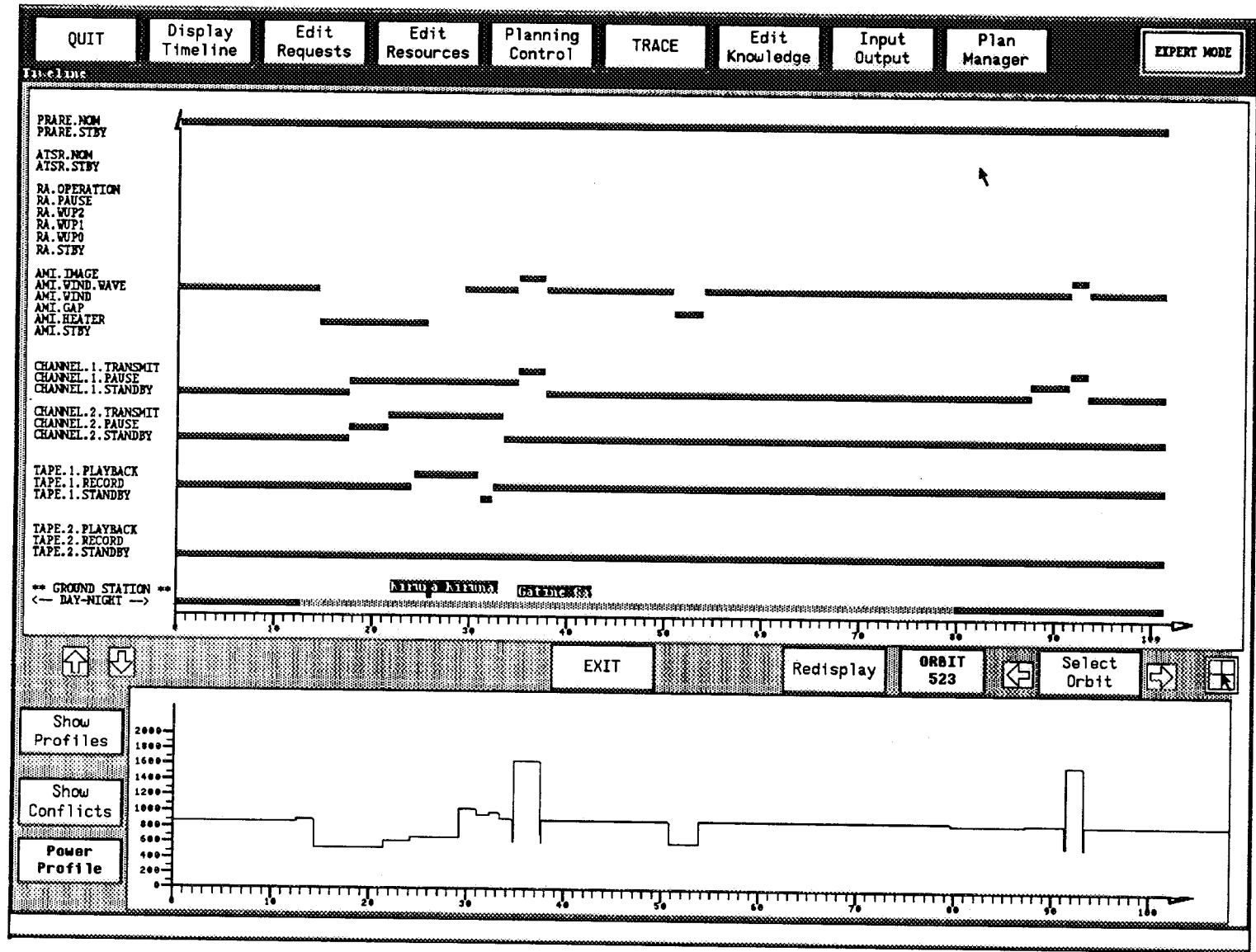
In this paper, we have presented three main areas where advanced software techniques can contribute to solve the requirements raised by

Mission Planning systems : performance, flexibility and genericity. Addressing these issues in future Mission Planning Systems is a major effort necessitated by the growing complexity of space systems in order to combine performance and flexibility without impacting on the global cost. Since this last aspect is becoming more and more crucial, the genericity issue is one of a major concern of space companies and agencies.

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Figure 1 : Planers Timeline representation. The various modes of the instruments are represented in the top window and the resource consumption (power in this case) is available in the bottom window.



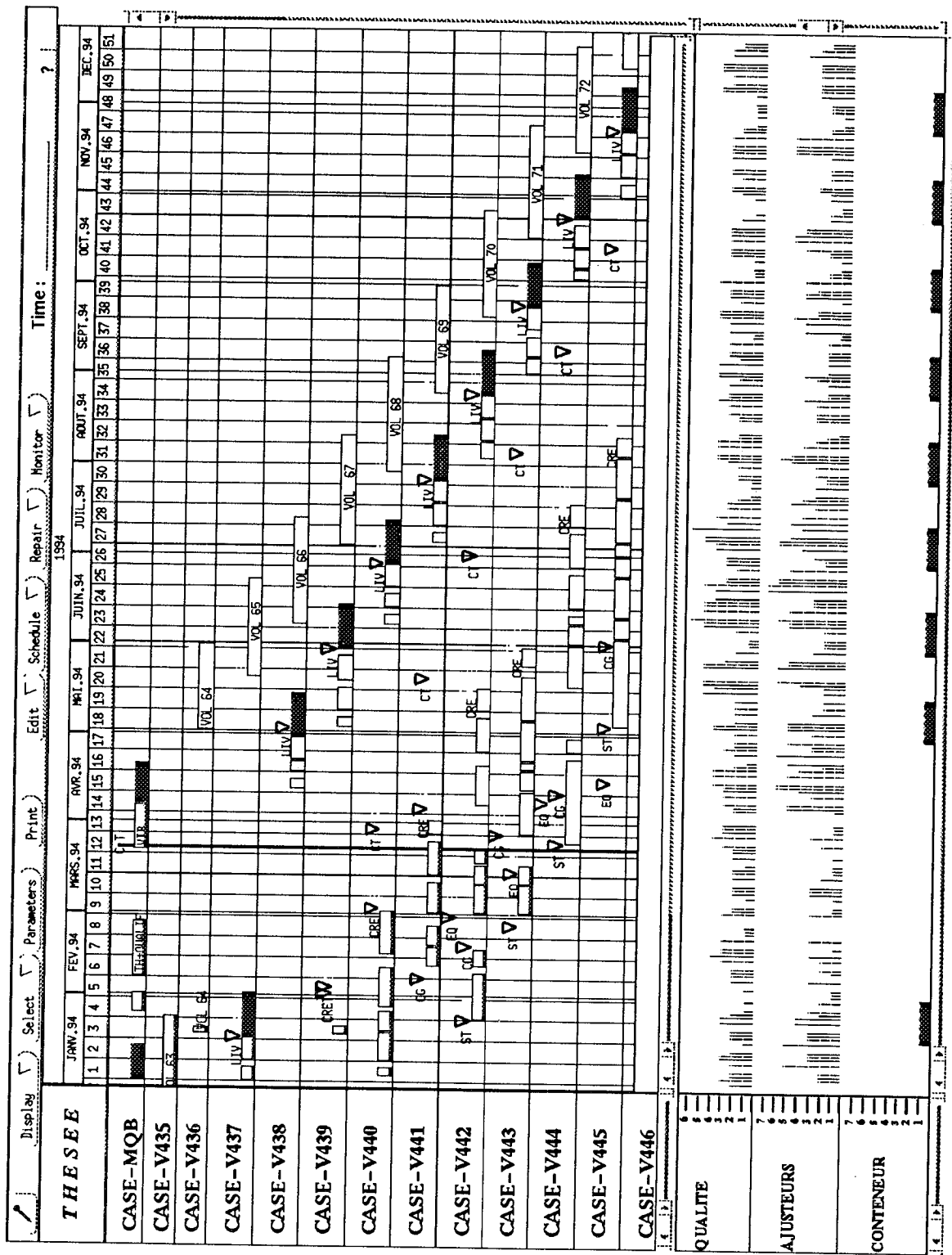


Figure 2 : Optimum Gantt representation. Activities are represented in the top window and re-sources consumption profiles are shown in the bottom window.